DE LA RECHERCHE À L'INDUSTRIE

# MAGNETIC HYGIENE

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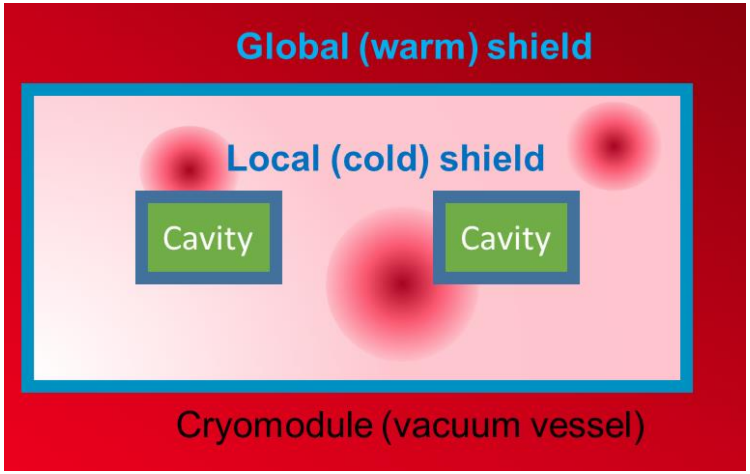
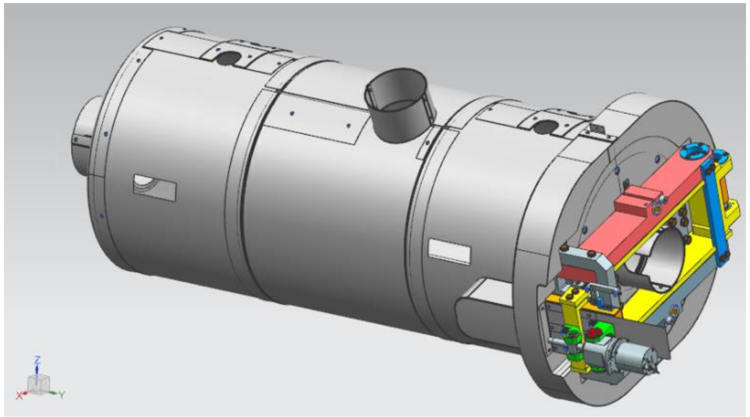
- Requirements for the PIP-II LB and HB cryomodules: field on the cavity surface must be below 5 mG (0.5 µT)




- To achieve this stringent requirement:
  - Vacuum vessel in carbon steel
  - Global and local shields to protect against Earth magnetic field
  - Local shield to protect against possible magnetized parts or parts that could be magnetized by superconducting solenoids (in case of HWR, SSR1 and SSR2)



But the local shield has openings (beam pipe, helium ports, lugs …) that could reduce its efficiency

**Need of a magnetic hygiene plan**

# MAGNETIC HYGIENE PLAN

**Goal** Proscribe presence of magnetized elements close to the cavity

**How**

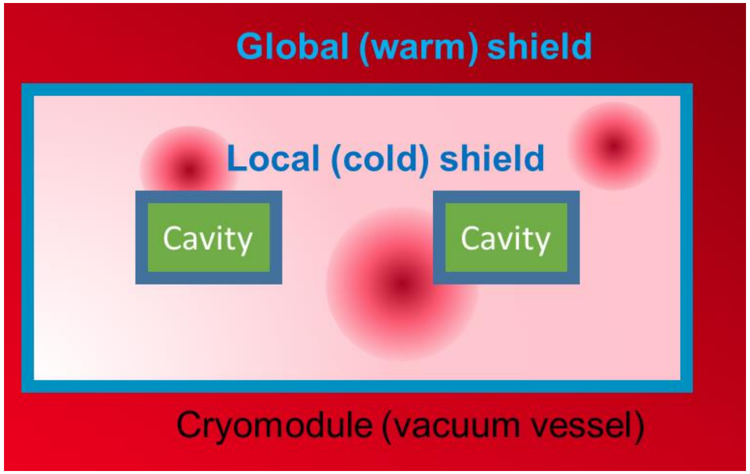
- ❑ Identification of the parts close to the cavities which could cause magnetic pollution.
- ❑ Material specification and certifications.
- ❑ Incoming material inspection.
- ❑ Inspection after manufacturing.

Normal procedure at CEA

- ❑ Demagnetization of the vaccum vessel before assembly and the complete cryomodule before the test

Required for PIP-II cryomodule

# Identification of the parts close to the cavities which could cause magnetic pollution




**Question:** how far must be a given element from the cavity?

**Answer:** far enough so radiated magnetic field is lower than minimum value allowed on cavity

**But…** how can this be predicted from element properties ?

**And in particular:** how can this be predicted from **raw material** properties?

*Courtesy of J. Plouin - CEA*

# SOME TESTS PERFORMED AT CEA

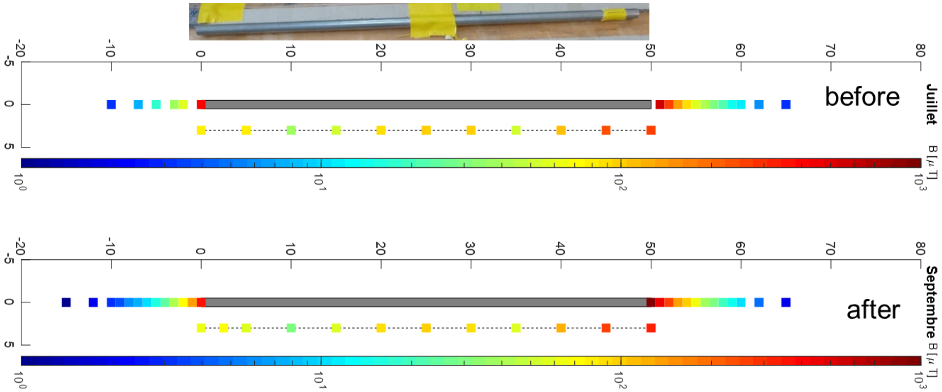
Performed at Saclay during the tests of the superconducting coils for the JT60-SA tokamak


- Tested parts: 3 supports made of stainless steel, 1 invar bar
- All parts have been characterized before / after:
  - Stainless steel supports : $\mu_r$ , surrounding field
  - Invar bar : surrounding field

Courtesy of J. Plouin - CEA

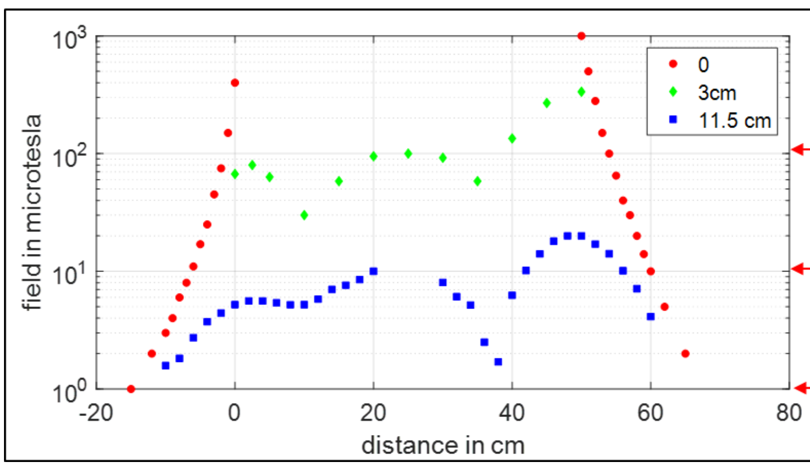
# INVAR ROD: RESULTS

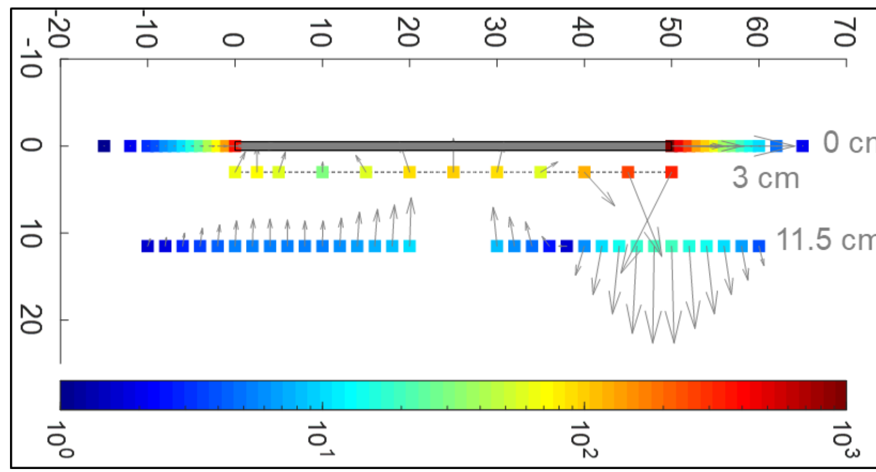
*Courtesy of J. Plouin - CEA*




- ❑ No significant difference before and after being exposed to a transverse field of 14 mT

- ❑ At 11.5 cm from the bar, the magnetic field goes up to 20 µT…

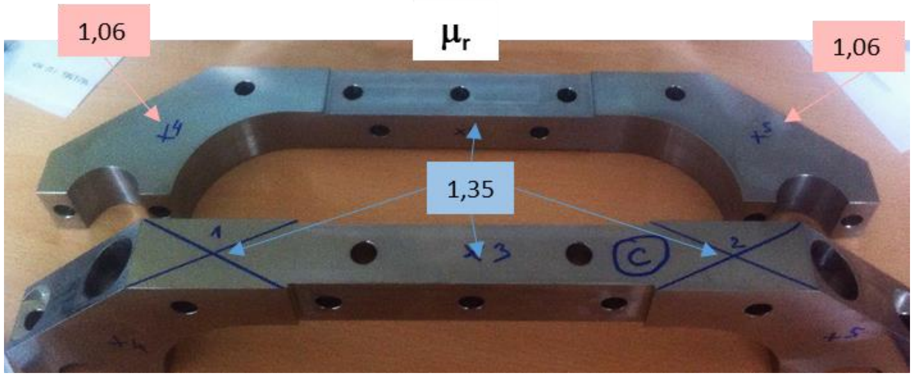


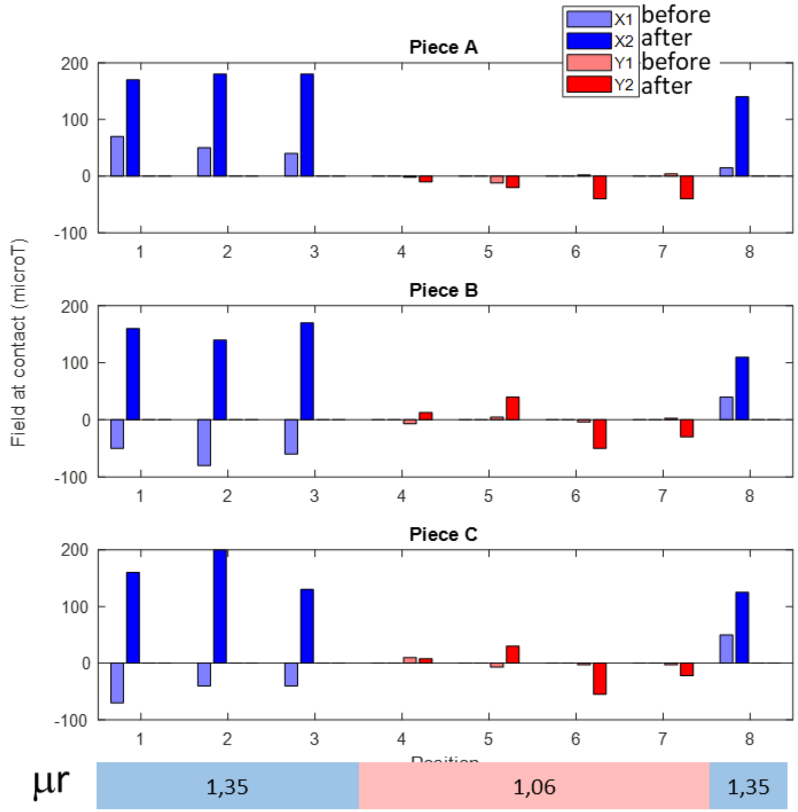




**Obviously, invar bar is a dangerous element …**

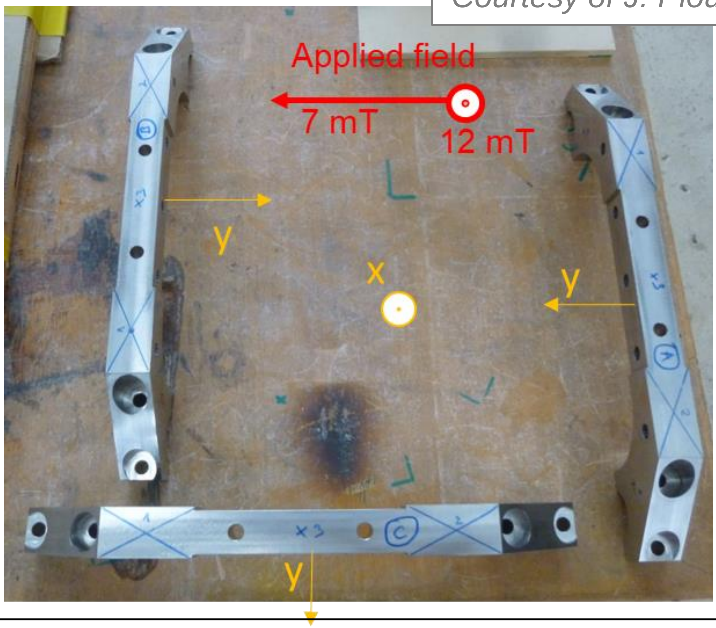
**But seems to be usable as implemented on XFEL and LCLS-II cryomodules**

# STAINLESS STEEL PARTS: RESULTS




*Courtesy of J. Plouin - CEA*



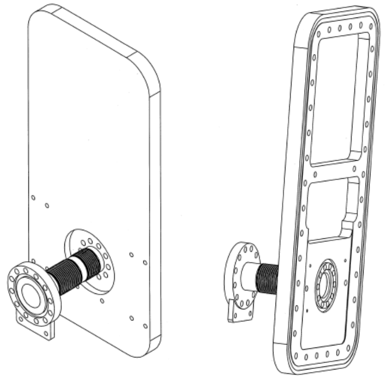

Conclusions:

For areas with $\mu_r$ = 1,35 : clear vertical magnetization : ≃200μT at contact.

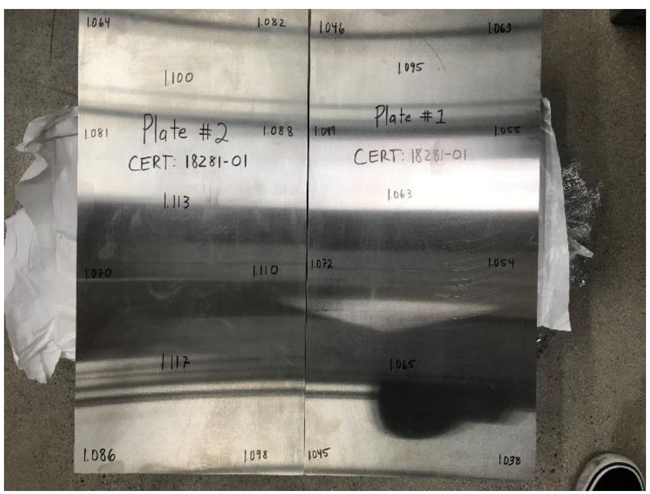
For areas with $\mu_r$ = 1.06 : magnetization has been modified but no clear effect of the applied field effect.

Important to fix a maximum magnetic permeability for parts in stainless steel

# SOME CEA EXPERIENCE WITH 316L STAINLESS STEEL PARTS



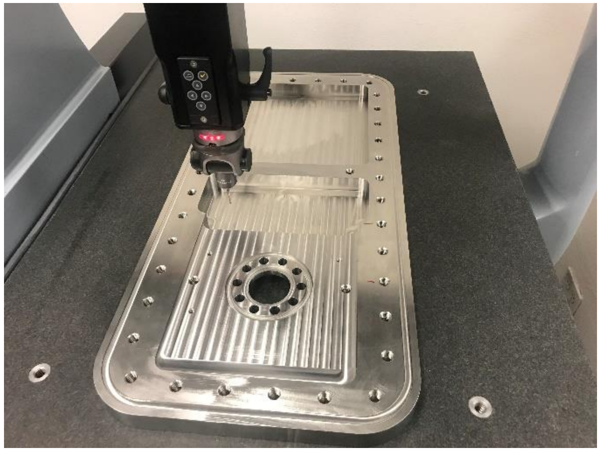
- ❑ Cold-warm transition from the IFMIF cryomodule: part made of a thick plate, bellows and a flange
- ❑ Requirement for the magnetic permeability: µr ≤ 1.02 (discussion later on this value)




- ❑ Procurement of the raw material for the thick plates was not an easy thing:
  - First procurement was rejected because of µr higher than the required value of 1.02
  - Second procurement: µr still too high, up to 1.12 → it was decided to anneal the plates
  - After annealing, µr was OK, but the plates were wrapped → need to be grinded
  - After grinding: µr was still OK, but the thickness was below the value specified on the drawings (24.2 mm instead of 25.0 mm) → no option but to accept it as is

TBC

# SOME CEA EXPERIENCE WITH 316L STAINLESS STEEL PARTS

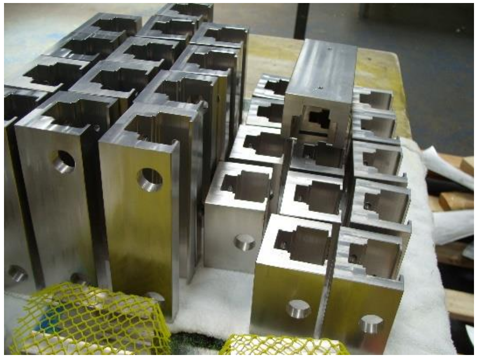


- ❑ Machining of the plates
  - Special care was taken → very long machining process
  - µr was OK

- ❑ Flange: after machining, µr was higher than required → annealed, no wrapping, process was under controlled after several attempts on samples

- ❑ Welding of the parts:
  - Use of a proper filler
  - After welding, µr up to 1.03 in some locations
  - This part is far from the superconducting cavities → accepted as it is

# SOME CEA EXPERIENCE WITH 316L STAINLESS STEEL PARTS



- C-blocks of the C-shaped elements: parts very close to the cavities
- Requirement for the magnetic permeability: μr ≤ 1.02

- First batch:
  - Raw material was not controlled by the contractor as required in the technical specifications
  - Machined parts were rejected by CEA (μr between 1.05 and 1.2)
- Second batch:
  - Raw material controlled by the contractor
  - After machining, μr was higher than required → parts were annealed
  - The annealing was not successful → parts rejected by CEA
- It was decided to change the material from 316L stainless steel to titanium grade 2

# SOME LESSONS LEARNT WITH 316L STAINLESS STEEL

- Procurement of “good” raw material is mandatory to achieve the required final magnetic permeability.
- BUT:
  - It is not always easy to find the proper raw material, especially on ingots or thick plates.
  - It does not guarantee that the part will be acceptable: machining and welding could have an impact on the permeability.
- My experience:
  - The permeability of the manufactured part strongly depends on the contractor.
  - Annealing could be a solution, but the process must be qualified.
  - Higher permeability could be acceptable on “small” parts in localized areas (example: small fillet radius).

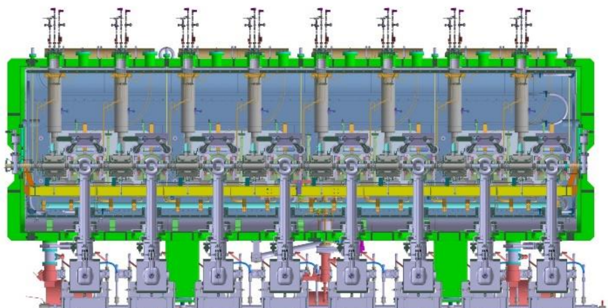
**QUESTION:** which criteria for the magnetic permeability for the PIP-II cryomodules?

- CEA usually requires $\mu r \leq 1.02$
- I found two FNAL documents with inconsistent requirements:
  - $\mu r \leq 1.02$ in the “Cryomodule Design Handbook - ED0011955”
  - $\mu r \leq 1.1$ in “Specification and Measurement Procedures of Magnetic Properties of Parts for PIP-II Cryomodule Assembly”

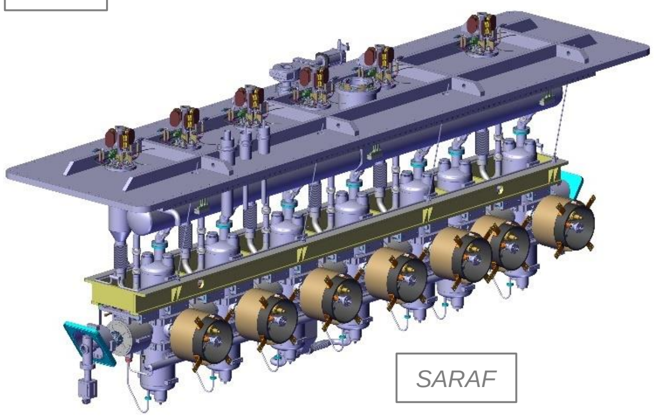
## My recommandations:

- ❑ Avoid 316L stainless steel for parts that are close to the cavities or magnets (superconducting solenoids, permanent magnets …)
- ❑ Use 316LN or titanium. It may be more expensive when placing the order, but time for controls is reduced and long discussions about the non-conformities and how to solve them are avoided, with no delay on the schedule

## Example of IFMIF and SARAF cryomodules



IFMIF



SARAF

- ❑ Cryomodules with half-wave resonators (HWR) and superconducting solenoids
- ❑ The frame that supports the cavity string in made of titanium grade 2

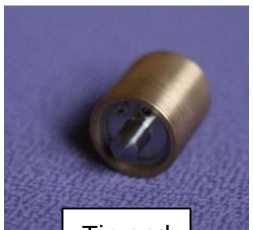
SARAF

IFMIF

# EXPERIENCE WITH SOME COMPONENTS OF THE C-SHAPED ELEMENTS

Making of mock-ups to perform assembly tests: no magnetic hygiene plan

## Spring loaded bushes


Tip end


Adjustment end

| Sample number | Tip end (µT) | Adjustment end (µT) | Threaded side(µT) |
|---|---|---|---|
| 1 | 14 | 6.7 | 16 |
| 2 | 62 | 11 | 52 |

Magnetic field measurement 10 mm away from the two bush samples

- Axis made of 316L
- But 26 µT at the round tip side

- Bush treaded tube made of copper-tin alloy (CuSn12)
- May be some traces of nickel or iron
- 7 µT at the adjustment end, 6 µT on the opposite side

- Beryllium copper (CuBe) washers
- Non magnetic (as expected)

- 304L circlip
- Stronly magnetized (1100 µT at the gap)

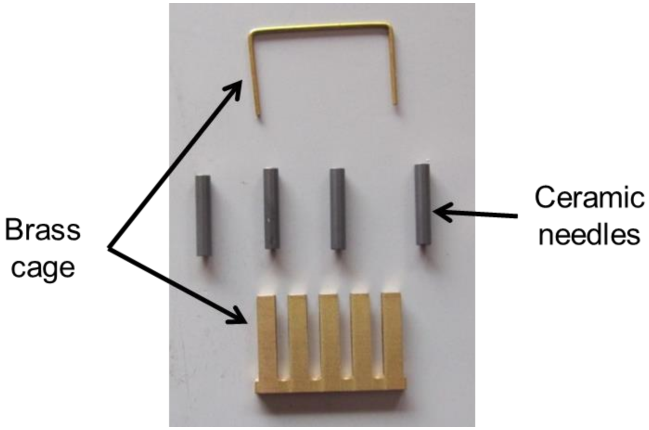
## Needle bearings

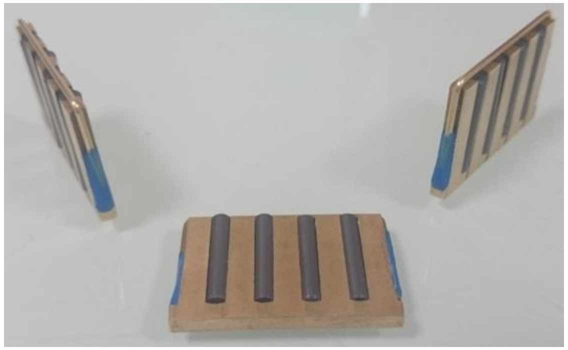
- ❑ Off-the-shelf bearings

| Sample number | Average value at 10 mm (µT) | Average value at 4 mm (µT) | Average value at contact (µT) |
|---|---|---|---|
| 1 | 5 | 10 | 25 |
| 2 | 25 | 72 | 220 |
| 3 | 60 | 50 | 140 |
| 4 | 42 | 100 | 215 |
| 5 | 34 | 80 | 135 |
| 6 | 5 | 19 | 39 |
| 7 | 42 | 105 | 440 |
| 8 | 16 | 70 | 235 |

Measurements performed on 7 units

- ❑ Homemade bearings were developed



# DISCUSSION

- Demagnetization:
  - Efficiency proven on LCLS-II cryomodules
  - For cryomodules with superconducting magnets: In-situ demagnetization after a quench? Before each cool-down?
- Close to / far from the cavity: what is the limit?
- Components close to the cavity: what is the maximum permeability?
- Components far from the cavity: what is the maximum permeability?